

resolution images of planets, extending studies of atmospheric motion begun with the Pioneer and Voyager probes, and will be capable of detecting certain classes of planets orbiting nearby stars. FUSE (highly recommended) could provide important ultraviolet spectroscopic data on planetary atmospheres, as could SIRTf (pending) and LDR (highly recommended) in the infrared. Great contributions to the study of the planets, particularly synoptic studies of their atmospheres, would be made by the Planetary Spectroscopy Telescope (PST; recommended), [71] which would have pointing and scheduling characteristics optimized for such studies.

Finally, spectroscopy of comets could be accomplished by a variety of missions such as ST (under development), FUSE (highly recommended), SIRTf (pending), and LDR (highly recommended) all of which will be sufficiently sensitive not only for emission-line measurements, but also for absorption-line observations, using background stars as continuum sources.

6. SUMMARY

Nearly every major research goal outlined in Chapter I can be accomplished, at least in part, by missions described in this report. A large fraction will be carried out by those listed as “under development”, “pending”, “highly recommended”, or “recommended”, so that prospects are strong for accomplishing much of what the MOWGSA sees as desirable before the end of this century. The success of this program depends not only on the specific missions mentioned in this section, but also on the supporting programs and technological developments outlined earlier.

The MOWGSA hopes that this planning document will prove to be useful in the coming years, as NASA seeks to carry its functions in space astronomy.

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The Space Science Board endorsed the development of a major space-based facility devoted to gamma-ray astronomy in 1976. A year later, NASA released an announcement of opportunity inviting scientists to propose instruments for the spacecraft, which became known as the Gamma-Ray Observatory (GRO). While five instruments were tentatively selected for definition studies, that list was narrowed to four when one of the experiments could not meet cost and programmatic constraints. President Jimmy Carter in 1979 approved the GRO for development in preference to a U.S. mission to comet Halley, because he was convinced that it would produce more important scientific data than would a comet mission. In September 1981, the GRO Science Working Team developed this science plan in light of the four experiments selected and the goal to keep total mission costs below \$100 million (FY 1981 dollars). These four instruments made up the payload of spacecraft, which took the name

Compton Gamma Ray Observatory, after physicist Arthur Holly Compton, when it was launched aboard the Space Shuttle in 1991. The Compton GRO spacecraft was purposely deorbited in 2000 because its control gyroscopes were failing.

[cover sheet]

THE GAMMA-RAY OBSERVATORY
SCIENCE PLAN
SEPTEMBER 1981

Prepared by: Gamma-Ray Observatory Science Working Team

[1] GAMMA-RAY OBSERVATORY SCIENCE PLAN

I. INTRODUCTION

Gamma-ray astronomy, the study of the highest energy electromagnetic radiation from the cosmos, occupies a unique position in the search for understanding the Universe. This high energy radiation is produced in a wide variety of astrophysical processes which would otherwise remain unobservable. These processes include nuclear reactions, matter-antimatter annihilation, elementary particle decays, and some general relativistic effects. The great penetrating power of gamma rays allows them to reach the top of the atmosphere [sic] from almost anywhere in the Universe. On the other hand, the atmosphere [sic] is opaque to gamma rays, and, hence, the observations must be made from space. The astrophysical sites where gamma-ray emission is a major source of energy release are some of the most energetic objects in the Universe—e.g., supernovae, neutron stars, black holes, cores of galaxies, and quasars. Among the problems addressed by gamma-ray astronomy are the formation of the elements in the Universe, the structure and dynamics of the Galaxy, the nature of pulsars, the possible existence of large amounts of antimatter in the Universe, phenomena occurring in the nuclei of galaxies—especially explosive galaxies—and the origin and evolution of the Universe itself. For many such problems, gamma rays are the only source of information about the high energy reactions taking place.

Because gamma-ray astronomy requires complex detectors operating outside the Earth's atmosphere, it is only in recent years that this field has begun to develop. The discoveries in gamma-ray astronomy parallel those in other new branches of astronomy in that the unexpected results have been as significant as those which had been predicted in providing new insight into a number of astrophysical problems.

[2] For example, it has been found that some pulsars emit several orders of magnitude more energy in the form of gamma rays than in the form of radio waves and that the quasar [sic] 3C273 appears to radiate as much energy in gamma rays as in any other form of electromagnetic radiation. Also, many energetic gamma-ray sources have been found which at present have not been correlated with objects observed at other wavelengths [sic]. These observations suggest the possibility of a class of celestial objects not previously known. Further, intense bursts of low energy gamma rays have been detected; the ori-

gin of these events remains a mystery. In all these cases, these objects cannot be fully understood without a thorough knowledge of their gamma-ray emission, because this emission represents such a significant fraction of the total radiated energy. The understanding of gamma-ray-luminous sources is one of the most important open problems for all astronomy.

Other important astronomical questions for which gamma-ray astronomy can provide decisive answers include nucleosynthesis, via the study of gamma-ray line emission; Galactic structure, as revealed by the gamma rays produced in the interactions of cosmic rays with interstellar matter; and the origin and evolution of the Universe, through observations of the isotropic gamma radiation. Beyond these known returns lies the anticipation of further unexpected results in gamma-ray astronomy as the sensitivity of the observations improves, particularly because much of the gamma-ray energy range is just now being explored and much of the gamma-ray sky has not been observed.

The Gamma-Ray Observatory (GRO), which will provide the first comprehensive, coordinated observations covering the entire spectrum of gamma-ray astronomy, with much better sensitivity than any previous mission.[sic]This approach requires four separate detector systems with quite different characteristics, each emphasizing a particular aspect of the observations.

[3] In this Science Plan for the GRO, Section II [not included] discusses in depth the scientific rationale for gamma-ray astronomy. Section III presents the specific scientific objectives for the GRO and describes how the four selected instruments have a combined capability to achieve these objectives. Section IV [not included] contains a summary of each of the four investigations chosen for the mission.

[21]

III. GAMMA-RAY OBSERVATORY

A. Scientific Objectives

Based on the foregoing scientific rationale and the recommendation of the Committee on Space Astronomy and Astrophysics of the National Academy of Science's Space Science Board, GRO has adopted the following scientific objectives:

- A study of discrete objects such as black holes, neutron stars, and objects emitting only at gamma-ray energies.
- A search for evidence of nucleosynthesis - the fundamental process in nature for building up the heavy elements in nature and other gamma-ray lines emitted in astrophysical processes.
- The exploration of the Galaxy in gamma rays in order to study the origin and dynamic pressure effects of the cosmic-ray gas and the structural features revealed through the interaction of the cosmic rays with the interstellar medium.
- A study of the nature of other galaxies as seen at gamma-ray wavelengths, with special emphasis on radio galaxies, Seyfert galaxies and QSO's.
- A search for cosmological effects, through observations of the diffuse gamma radiation, and for possible primordial black hole emission.
- Observations of gamma-ray bursts, their luminosity distribution, the spectral and temporal characteristics and their spatial distribution.

[22] In the section that follows, a brief description of the observatory requirements necessary to achieve these objectives, the specific spacecraft parameters needed to support these requirements and a brief description of the instruments to be used in these observations will be presented.

B. Observatory Requirements

To achieve these scientific objectives, the Gamma-Ray Observatory must be capable of conducting a comprehensive survey of the gamma-ray sky over an energy range extending from the upper end of existing x-ray observations up to the highest practical energy. The GRO sensitivity for discrete sources, diffuse radiation, and gamma-ray lines should be significantly greater than any previous instruments.

No single scientific instrument is capable of meeting all the requirements. The band of wavelengths encompassed by gamma-ray astronomy is more than 100 times as broad as that of x-ray astronomy, and more than 104 times broader than the visible region. Different detection methods are needed in different parts of the gamma-ray spectrum. Further, even within a part of the energy range, energy and angular resolution can usually be improved only at the expense of sensitivity. A complementary set of experiments is required, therefore, in order to meet the scientific objectives. The spacecraft supporting these instruments must be capable of pointing them accurately and with stability to any part of the sky for a period of two weeks, provide adequate power and thermal control, supply attitude and timing data as precise as needed by the instruments, and handle the data from all these instruments efficiently.

[23] C. Spacecraft Summary

The Gamma-Ray Observatory will be a shuttle-launched, free-flyer satellite. The nominal circular orbit will be about 400 kilometers with an inclination of 28.5° . The radius should remain below 450 kilometers to prevent excessively high trapped particle dosages during passage through the South Atlantic Anomaly [sic]. An orbital radius below about 350 kilometers causes excessive aerodynamic drag on the Observatory. The spacecraft must be capable of accommodating 5500 kilograms of instruments and must supply 600 watts of experiment power. The 17 kilobits per second of experiment data will be supported via NASA's Tracking and Data Relay Satellite system. Celestial pointing to any point on the sky (excluding the Sun) will be maintained to an accuracy of $\pm 0.5^\circ$. This is determined by the precision to which exposure to a given region of the sky must be known in order to determine the sensitivity of an observation. Knowledge of the pointing direction will be determined to an accuracy of 2 arc minutes so that this error contributes negligibly to the over all determination of the direction of gamma-ray source. Absolute time will be accurate to 0.1 milliseconds to allow precise comparisons of pulsars and other time varying sources with observations at other wavelengths from ground observations and other satellites. The attitude and timing data together with orbital position will be encoded into the telemetry data. These spacecraft support requirements are summarized in Table I.

[24]

Table I

SPACECRAFT SUPPORT REQUIREMENTS

Scientific Payload Weight	5500 kilograms
Instrument Power	600 watts
Experiment Data Rate	17 kilobits
Pointing Accuracy	$\pm 0.5^\circ$
Attitude Determination	2 arc minutes
Absolute Timing Accuracy	0.1 milliseconds

Brief capsule descriptions of each experiment are given as follows: More detailed [sic] descriptions can be found in Section IV.

1. Gamma-Ray Observatory Scintillation Spectrometer (OSSE):

This experiment utilizes four large actively-shielded and passively-collimated-Sodium Iodide (NaI) Scintillation detectors, with a $5^\circ \times 11^\circ$ FWHM field of view. The large area detectors provide excellent sensitivity [sic] for both gamma-ray line and continuum emissions. An offset pointing system modulates the celestial source contributions to allow background subtraction. It also permits observations of off-axis sources such as transient phenomena and solar flares without impacting the planned Observatory viewing program.

[25] 2. Imaging Compton Telescope (COMPTEL):

This instrument is based on a newly established concept of gamma-ray detection in the 1-30 MeV range. It employs the unique signature of a two-step absorption of the gamma-ray, i.e., a Compton collision in the first detector followed by total absorption in a second detector element. This method, in combination with effective charged particle shield detectors, results in a more efficient suppression of the otherwise inherent instrumental background. Spatial resolution in the two detectors together with the well defined geometry of the Compton interaction permits the reconstruction of the sky image over a wide field of view (~ 1 steradian) with a resolution of a few degrees. In addition, the instrument has the capability of searching for polarization of the radiation. The instrument has good capabilities for the search for weak sources, weak galactic features and for the search for spectral and spatial features in the extragalactic diffuse radiation.

3. Energetic Gamma-Ray Telescope (EGRET):

The High Energy Gamma-Ray Telescope is designed to cover the energy range from 20 MeV to 30×10^3 MeV. The instrument uses a multi-thin-plate spark chamber to detect gamma rays by the electronpositron pair process. A total energy counter using NaI(Tl) is placed beneath the instrument to provide good energy resolution over a wide dynamic range. The instrument is covered by a plastic scintillator anticoincidence dome to prevent readout on events not associated with gamma rays. The combination of high energies and good spatial resolution in this instrument provides the best source positions of any GRO instrument.

[26] 4. Burst and Transient Source Experiment (BATSE):

The Burst and Transient Source Experiment for the GRO is designed to continuously monitor a large fraction of the sky for a wide range of types of transient gamma-ray

events. The monitor consists of eight wide field detector modules. Four have the same viewing path as the other telescopes on GRO and four are on the bottom side of the instrument module viewing the opposite hemisphere. This arrangement provides maximum continuous exposure to the unobstructed sky. The capability provides for 0.1 msec time resolution, a burst location accuracy of about a degree and a sensitivity of 6×10^{-8} erg/cm² for a 10 sec burst.

The salient features of the four experiments are summarized in Table II. As mentioned above, each instrument represents a significant step forward over its predecessors. For example, the sensitivity for line gamma-ray detection has been improved by more than an order of magnitude over the HEAO-A4 and HEAO C-1 instruments. The continuum sensitivity in the MeV range is typically improved by a factor of twenty or more. Improvements of about an order of magnitude in source location capability are also expected due to the improved instruments and the greatly increased exposure factors. The addition of a massive NaI calorimeter crystal has markedly improved the energy resolution (a factor of 2 better than SAS-2) in the > 100 MeV range and extended the range to 20 GeV. Also in this range the total effective area (i.e., area X geometry factor) is 25 times larger than that of COS-B.

[27]

Table II
SUMMARY OF GRO DETECTOR CHARACTERISTICS

	<u>OSSE</u>	<u>COMPTEL</u>	<u>EGRET</u>	<u>BATSE</u>
Energy Range (MeV)	0.10 to 10.0	1.0 to 30.0	20 to 3×10^4	0.05 to 0.60
Energy Resolution	8.0% at 0.66 MeV	5 - 8%	15%	35% at 0.1 MeV
Maximum Effective Area (cm ² efficiency)	2310	50	2000	5500
Position Resolution (strong source)	10 arc min square error box (special mode)	7.5 arc min (1 σ radius)	5 arc min. (1 σ radius)	1°
Maximum Effective Geometric Factor (cm ² sr efficiency) [sic]	12	30	1000	15000
Estimated Threshold Line	$2 \times 10^5 \text{ cm}^2 \text{ s}^{-1}$	3×10^5 to 3×10^6		0.1 Crab-
(source sensitivity) Continuum	$\sim 3 \times 10^5 \text{ cm}^2 \text{ s}^{-1}$	$5 \times 10^5 \text{ cm}^2 \text{ s}^{-1}$	$5 \times 10^8 \text{ cm}^2 \text{ s}^{-1}$	transient $6 \times 10^8 \text{ erg cm}^2 \text{ burst}$
Weight (Kg)	1730	1477	1708	570
Average Power (watts)	140	195	170	100
Height (m) x Width (m)	1.5x(1.5x2.3)	2.8x1.7	2.25x1.65	0.7x0.6x0.7
Bit Rate (kbps)	6.0	4.5	5.0	1.5